Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked-Up Version of the Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) is respectfully requested.

The underlying PCT Application No. PCT/DE00/03547 includes an International Search Report, dated February 21, 2001. The Search Report includes a list of documents that were uncovered in the underlying PCT Application. A copy of the Search Report accompanies this Preliminary Amendment.

Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,
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INTERFEROMETRIC MEASURING DEVICE FOR MEASURING SHAPE

[Background Information
] **FIELD OF THE INVENTION**

The present invention relates to an interferometric measuring device for measuring the shape especially of rough surfaces of a measured object, having a radiation-producing unit emitting short-coherent radiation, a beam splitter for forming a first and a second beam component, of which the first is directed via an object light path to the measured object and the second is directed via a reference light path to a reflective reference plane, having a superposition element at which the radiation coming from the measured object and the reference plane are brought to superposition, and an image converter which receives the superposed radiation and sends corresponding signals to a device for evaluation, the optical path length of the object light path being changed relative to the optical path length of the reference light path.

BACKGROUND INFORMATION

Interferometric [Such an interferometric] measuring device**s** [is] **are** known from German **published patent document No.** [DE] 197 21 842 [C2]. In the case of this [known] **conventional** measuring device, a radiation-producing unit, such as a light-emitting diode or a superluminescent diode, emits a short-coherent radiation, which is split via a beam splitter into a first beam component guided over an object light path, and a second beam component guided over a reference light path. The reference light path is periodically changed, using two deflector elements and a stationary diffraction grating positioned behind it, by activating the deflector elements, so

as to scan the object surface in the depth direction. If the object light path and the reference light path coincide, a maximum interference contrast results, which is detected using an evaluation device post-connected to the photodetector device.

An interferometric measuring device representative of the measuring principle (white-light interferometry or short-coherent interferometry) is also specified in German **published patent document No.** [DE] 41 08 944 [A1]. Here, however, a moved mirror is used to change the light path in the reference ray path. In this method, the surface of the object is imaged on the photodetector device, using an optical system, it being difficult, however, to conduct measurements in cavities.

Additional such interferometric measuring devices and interferometric measuring methods based on white-light interferometry are described by P. de Groot, L. Deck, "Surface Profiling by Analysis of white-Light Interferograms in the Spatial Frequency Domain" J. Mod. Opt., Vol. 42, No. 2, 389-401, 1995 and No. T. Maack, G. Notni, W. Schreiber, W.-D. Prenzel, "Endoskopisches 3-D-Formmesssystem",(Endoscopic 3-D Shape Measuring System) in Jahrbuch für Optik und Feinmechanik, Ed. W.-D. Prenzel, Verlag (publisher) Schiele und Schoen, Berlin, 231-240, 1998 [verwiesen] (submitted).

In the case of the interferometric measuring devices and measuring methods named, one difficulty is making measurements in deep cavities or narrow ducts. One suggestion for a measuring device in which measurements [can] **may** be performed even in cavities, using white-light interferometry, is [shown] **described** in German **published patent document No.** [DE] 197 21 843 [C1]. It is [proposed] **described** there to split a first beam component further into a reference beam component and at least one measuring beam component, an additional beam

splitter and the reference mirror being positioned in a common measuring probe. To be sure, such a measuring probe [can] **may** be introduced into cavities, however, using this device, in each measurement, only a small, dot-like location in the surface [can] **may** be scanned. In order to take the measure of more locations on the surface in the depth direction, relative motion between measured object and measuring probe is required, an exact lateral coordination, however, being costly and difficult.

SUMMARY

The object of the present invention is to make available an interferometric measuring device, of the kind mentioned at the outset, which especially makes possible simplified measurements in deep cavities with great accuracy.

[This object is achieved by the features of Claim 1.] According to [this] **the present invention** it is provided that an optical probe in the object light path, having an optical device for generating at least one optical intermediate image, be provided.

Similarly to an endoscope or a borescope, in using the optical device, because of the intermediate images, it becomes possible to image the observed surface, besides using high longitudinal resolution, also at high lateral resolution over a path which [is] **may be** long compared to the diameter of the imaging optics. For example, the optical probe [can] **may** be introduced into the bores of valve seats or into vessels of organisms for the purpose of medical measurements. In contrast to the usual endoscope, quantitative depth information [is] **may be** now obtained. In this connection, an [advantageous] **example** embodiment [is] **may be** one in which the at least one intermediate image is generated in the object light path. For this, the same optical device [is] **may be** used for illuminating the measured location on the measured object as

for transmitting the radiation coming from the measured object to the photodetector device, if it is provided that both the radiation going to the measured object and the radiation coming back from it pass through the optical probe.

The optical image on the photodetector device [can] **may** be improved by providing, in the reference light path, an equal, further optical probe or at least a glass device for compensating for a glass proportion present in the optical probe with regard to the elements for the intermediate image(s).

A favorable construction, as far as handling is concerned, [is] **may be** one in which the optical motion difference between the first and the second arm is greater than the coherence length of the radiation; the radiation coming from the first mirror and the reflecting element [are] **may be** guided through a common optical probe (common path) using a further radiation portion; in the optical probe, a reference mirror is arranged at such a distance from the measured object that the motion difference between the first mirror and the reflecting element is canceled, and one part of the radiation incident on the reference mirror is reflected to the photodetector device and one part is allowed to pass through to the measured object and is reflected from there to the photodetector device. A further benefit of this design [is] **may be** that the object and reference waves pass through virtually the identical optics assembly, so that aberrations [are] **may be** substantially compensated for. Moreover, this set-up [is] **may be** more resistant to mechanical shocks. In this connection, two **example** embodiment possibilities [are] **may be,** for the reference mirror**,** [to be] provided on a flat face-plate or on a prism.

In this connection, handling [can] **may** further be simplified by arranging a fiber optic element between the beam splitter

and the further beam splitter.

In this design too, splitting essentially into a probe part and a part having a modulation arrangement [is] **may be** realized, handling being also favored.

The present invention is [elucidated] **described** in the following on the basis of [exemplary] **example** embodiments, with reference to the drawings. [The figures show:]

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 [a first exemplary] **illustrates an example** embodiment of an interferometric measuring device having an optical probe in a measured light path.

Figure 2 [a second exemplary] **illustrates an example** embodiment in which an optical probe is provided both in the measured light path and in the reference light path.

Figure 3 **illustrates an embodiment** [a design] of the interferometric measuring device having a common reference and measured light path.

Figure 4 [a further exemplary] **illustrates an example** embodiment in which, compared to Figure 3, fiber optics are provided between the first and a further beam splitter.

Figure 5 [a further design] **illustrates a further** example **embodiment** of the interferometric measuring device.

DETAILED DESCRIPTION

Figure 1 [shows] **illustrates** an interferometric measuring device having a radiation-producing unit SLD emitting short-coherent radiation, as, for example a light-emitting diode or a superluminescent diode, whose radiation [is] **may be**

split by a beam splitter ST1 into a first beam component T1 of a measured light path and a second beam component T2 of a reference light path. The design [is] **may be** like that of a Michelson interferometer. In the reference light path, the second beam component [is] **may be** reflected by a reference plane in the form of a reference mirror RSP, the reference light path being periodically changed by moving the reference mirror RSP or by acoustooptical deflectors, as described in German **published patent document No.** [DE] 197 21 842 [C2], mentioned at the outset. If the change of the light path [is] **may be** performed using two acoustooptical deflectors, a mechanically moved reflecting element becomes unnecessary, but instead, a fixed element, [particularly] **e.g.,** a diffraction grating, [can] **may** be used. By using a glass block G, the dispersion of an optical probe OSO arranged in the object light path [can] **may** be corrected as necessary.

In the object light path, the radiation [is] **may be** coupled into optical probe OSO, so that the radiation illuminates the surface to be measured of measured object O. The surface of the object [is] **may be** imaged by optical probe OSO via one or more intermediate images on photodetector equipment in the form of an image converter or image sensor BS, for instance, a CCD camera. The image of measured object O on image sensor BS [is] **may be** superposed with the reference wave of the second beam component. A high interference contrast occurs in the image of measured object O when the path difference in the reference light path and the measured light path is less than the coherence length. With regard to this, the measuring principle [is] **may be** based on white-light interferometry (short-coherent interferometry), as is described in greater detail in the documents mentioned at the outset. The length of the reference light path [is] **may be** varied over the entire measuring range for scanning in the depth direction of the surface to be measured, the length of the reference light path

being detected for each measured point at which the greatest interference contrast appears. It [is made] **may be** possible by the intermediate images to image the surface of the measured object at a high lateral resolution over a range that is large compared to the diameter of the imaging optics. Optical probe OSO resembles an endoscope and a borescope, however, the illumination and the feedback of the radiation coming from the measured surface via the same optical device occurring via at least one intermediate image. Figure 1 [shows] **illustrates** schematically some lenses L as further imaging elements. The actual intermediate images [are] **may be** created in optical probe OSO.

For applications, in which an exact compensation for the influence of the imaging lenses of optical probe OSO is required, the same optical probe OSR is also integrated in the reference light path or reference arm between beam splitter ST1 and reference mirror RSP as in the object light path between beam splitter ST1 and measuring object O, as [shown] **illustrated** in Figure 2.

In a modified design according to Figure 3, the interferometric measuring device may also be realized as a device having common reference and measuring arms (common path device). The interferometric measuring device [is] **may be** again illuminated by a short-coherent (broadband) radiation-producing unit. Beam splitter ST1 splits the light in two arms into first beam component T1 and second beam component T2, first beam component T1 falling on a first, fixed mirror SP1, and second beam component T2 falling on reflecting element RSP in the form of a reference mirror.

The optical path difference between the arms thus formed is greater than the coherence length of the radiation produced by radiation-producing unit SLD. Starting from the two mirrors SP1 and RSP, the reflected radiation is fed to optical probe

OS via beam splitter ST1 and a further beam splitter ST2. The special quality of this design [is] **may be** that there is a reference mirror RSP2 in optical probe OS itself.

A part of the radiation [is] **may be** reflected by this reference mirror RSP2, while the other part of the radiation illuminates the surface to be measured. Reference mirror RSP2 may be mounted on flat face-plate or on a prism. By using a prism, the wave front of the radiation illuminating the object surface, i.e. of the object wave [can] **may** be adapted to the geometry (e.g. inclination) of the surface to be measured. With the aid of optical probe OS, measured object O [is] **may be** in turn imaged via one or more intermediate images on image sensor BS, and superposed by the reference wave. In order to obtain height information, reflecting element RSP [is] **may be** made to traverse the measuring range, or changing the light path [is] **may be** undertaken as described above. In the image of measured object O great interference contrast appears when the path difference between fixed mirror SP1 and reflecting element RSP or of the light paths of the two arms is exactly the same as the optical path difference between reference mirror RSP2 and measured object O. In order to obtain the height profile, [known] **conventional** methods for detecting the greatest interference contrast [are] **may be** used in each image point (pixel). The benefit of this design [is] **may be** that the object and reference waves pass through virtually the identical optics assembly, so that aberrations [are] **may be** substantially compensated for. Moreover, this set-up [is] **may be** more rugged and, therefore, less susceptible to mechanical shocks.

For even simpler handling of the measuring device, the radiation of beam splitter ST1 [can] **may** also be transmitted to further beam splitter ST1, using fiber optics LF, as is [shown] **illustrated** in Figure 4.

A further alternative design is [shown] **illustrated** in Figure 5. As an alternative to the design having the common reference path and measuring light path as in Figures 3 and 4, a combined Mach-Zehnder-Michelson arrangement is provided. Again, a broadband radiation-producing unit SLD [is] **may be** used, whose radiation [is] **may be** coupled into a fiber optic element. First beam splitter ST1 splits the radiation into an object arm OA and a reference arm RA. In object arm OA, first beam component T1 [is] **may be** coupled out of the corresponding light conducting fiber and coupled into optical probe OSO via further beam splitter ST2, so that the surface to be measured of measured object O [is] **may be** illuminated. The object surface [is] **may be** imaged by optical probe OSO via one or more intermediate images on image sensor BS. In reference arm RA light [is] **may be** coupled out of the corresponding light-conducting fiber, [is] **may be** then propagated, if necessary, through the same optical probe OSR as [is] **may be** applied in object arm OA, and [is] **may be** coupled in by a second fiber coupler R2 to a light-conducting fiber positioned there. The reference wave reaches further beam splitter ST2 via the light-conducting fiber. There it [is] **may be** uncoupled and superposed with the object wave on image sensor BS via further beam splitter ST2. In both arms, the optical paths in the air, in optical probes OSO or OSR as well as in the light-conducting fibers have to be adjusted. Tuning of the path lengths in reference arm RA [is] **may be** performed here, for example, by shifting second fiber coupler R2, so that the optical air path in the reference arm [is] **may be** changed.

[Abstract
] **ABSTRACT**

An [The present invention relates to a] interferometric measuring device for measuring the shape [especially] of rough surfaces of a measured object **is provided.** [(O), having] **The device includes** a radiation-producing unit [(SLD)] emitting short-coherent radiation, a beam splitter [(ST1)] for forming a first and a second beam component [(T1, T2)], of which the first [is] **may be** directed via an object light path to the measured object [(O)], and the second [is] **may be** directed via a reference light path to a reflecting reference plane**.** [(RSP), having] **The device also includes** a superposition element at which the radiation coming from the measured object [(O)] and the reference plane [(RSP) are] **may be** brought to superposition, and an image converter [(BS)], which receives the superposed radiation and sends corresponding signals to a device for evaluation, for the measurement to be taken, the optical path length of the object light path being changed relative to the optical path length of the reference light path. An exact measuring of object surfaces in narrow cavities, in three dimensions, having great accuracy, [is] **may be** made possible by providing in the optical light path an optical probe [(OS, OSO)] having an optical arrangement for producing at least one optical intermediate image.